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Use of Toxic Screening Models for Drinking Water Utility Management

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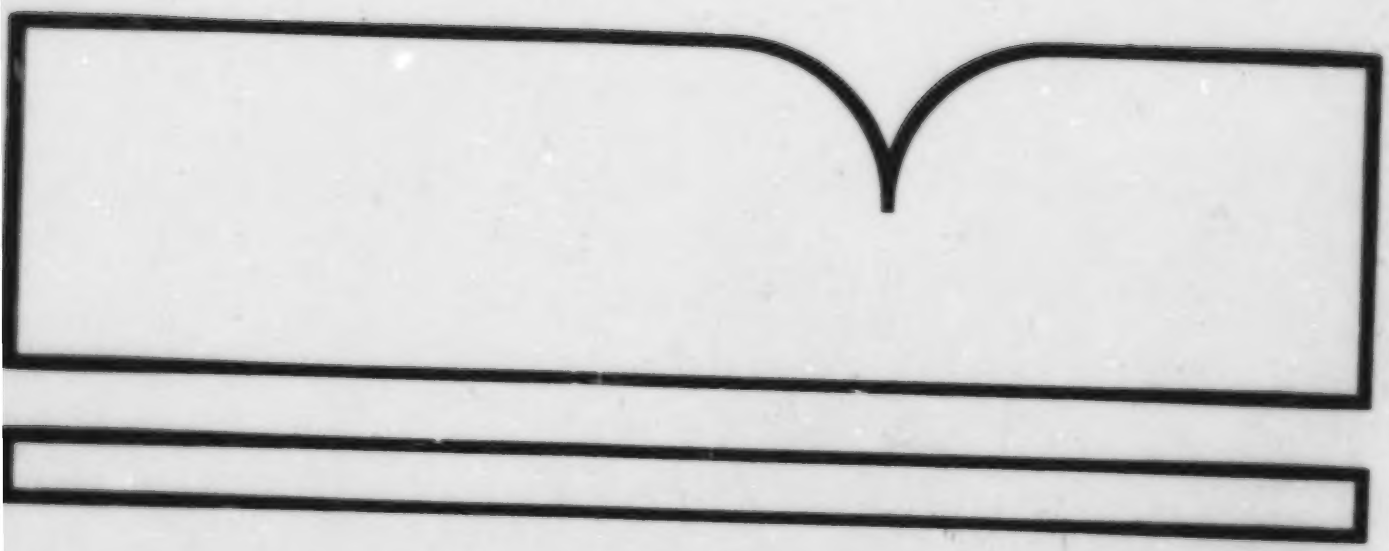

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USE OF TOXIC SCREENING MODELS FOR DRINKING WATER UTILITY MANAGEMENT

by

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- identification and assessment of communities whose water supplies could be vulnerable to synthetic organics resulting from industrial and municipal discharges, or urban and agricultural runoff,
- design and implementation of a water quality monitoring program, and
- other water resource planning efforts requiring information on the water quality of surface waters.

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ABSTRACT

Toxic Screening Models, as described in this paper, provide an approach for identifying and assessing the pollutants that are likely to be present in surface waters used as water supplies. Specific uses of these models include the following:

- identification and assessment of communities whose water supplies could be vulnerable to synthetic organics resulting from industrial and municipal discharges, or urban and agricultural runoff
- design and implementation of a water quality monitoring program
- other water resource planning efforts requiring information on the water quality of surface waters.

KEY WORDS: Toxic Discharges; Water Supply; Vulnerability; Carcinogens; Organoleptic Pollutants; Treatment Costs

1. INTRODUCTION

The Environmental Protection Agency has recently adopted a unified basis for assessing environmental risk. This approach entails a two-step approach.[1] The first step is risk assessment or characterizing the nature and extent of the risk, the second step is risk management or deciding what to do about the problem. In this paper environmental risk management will be addressed as it relates to drinking water utility management. The use of toxic screening models for identifying and estimating pollutants likely to be present in surface waters and for identifying drinking water utilities that are vulnerable to upstream discharges will be examined.[2] Once this concept has been developed it will be extended to the design and operation of water treatment systems or technology to reduce risk from these discharges to the consumer population.

2. RISK MANAGEMENT IN WATER SUPPLY

The concepts of risk management and risk evaluation in water supply are not new, although the terminology is new. The link between risk assessment and regulatory action was first established by promulgation of the interstate quarantine regulations of 1894. One of the first of these regulations was the banning of the common drinking water cup on interstate carriers. Banning of the cup met strong opposition. Opponents of banning the cup advanced the hypothesis that if the cups became unavailable for any reason the crowd so deprived of drinking water facilities would have its health seriously endangered, and in fact, might even be forced to succumb to the obvious temptation of alcoholic beverages.[3] A more dramatic example of the risk assessment, and one that can be quantified, occurred in the late 1800's, when waterborne disease was prevalent in the U.S. Figure 1 illustrates the typical reduction in typhoid that took place as a result of the application of water treatment and chlorination.

"figure 1 about here"

This particular example is constructed from data that was taken from the Cincinnati Waterworks in the period between 1897 and 1928. As you can see from Figure 1, prior to the introduction of filtration, the typhoid case rate had climbed to 500/100,000 and the death rate was close to 100/100,000. The introduction of filtration in 1907 reduced the case rate to 50/100,000 people and the death rate to 5/100,000 people by 1910. In 1915 chlorination began, and reduced both the case rate and the death rate to a negligible level.[4] Even with the dramatic reduction in waterborne disease outbreaks there was still great disagreement as to the cost-effective nature of treatment.

Many arguments were heard against the installation of water treatment and disinfection.

3. SAFE DRINKING WATER ACT

During the period after the interstate quarantine a number of contaminants in drinking water were identified as public health hazards.

In 1974 Congress passed the Safe Drinking Water Act in an attempt to deal with risk evaluation in drinking water in a structured manner.[5] One of these issues addressed in the Act is that of toxic waste discharges discharges and their effects on water supply. With the advent of the post World War II chemical revolution the character of water quality problems in surface water changed from waterborne disease to toxic waste discharges. Various surveys documented the presence of a number of synthetic organic chemicals in drinking water sources.

In 1974 Harris attempted to link cancer death rates with the presence of synthetic organics in New Orleans' drinking water supply.[6] In 1978 EPA issued a proposed two-part regulation dealing with organics in drinking water. Part A dealt with controlling the formation of trihalomethanes through the disinfection process.[7] Part B was an attempt to promulgate a GAC treatment technology. In order to promulgate Part B the Agency was required to define the concept of a vulnerable utility. Because of EPA's inability to do so, Part B was dropped. In the late 1970's, a massive carbon tetrachloride spill occurred in the Kanawha River in West Virginia, causing panic in many cities along the Ohio River, including Cincinnati, and causing Cincinnati's water intakes to be closed for 2 days.

In 1982, EPA's Drinking Water Research staff was approached by the City of New Orleans with a request for technical assistance in defining New Orleans' vulnerability to upstream discharges and spills. EPA was at that time conducting research into techniques that could be used to define the concept of vulnerability. The results of this research and its extension to two case study applications will be discussed in the following sections.

4. VULNERABILITY

The approach taken was to examine the concept of vulnerability in the context of a case study. The case study area chosen was the Ohio River Basin from the Kanawha River to the Cincinnati metropolitan area. A number of different factors were examined. These factors included the following: the amounts and characteristics of discharges upstream of a given utility; the flow characteristics of the river; the physical persistence of the discharge; and the storage capacity of the utility.[2]

A key factor in this approach was the use of a water quality model that reflects the spatial nature of the problem. The model selected was QUAL-II.

Many data sources were examined. Data from NPDES permits and special studies were used to characterize various industry point sources in the study area. Industrial discharges were characterized according to SIC code and waste stream data were estimated from EPA compliance data. Nonpoint sources were not examined.

The utilities in the case study area supplied information on storage capacity. Flow and velocity data were obtained from the

U.S.G.S., ORSANCO and the U.S. Army Corps of Engineers. Scientific and technical documents, supplied information on the behavior of various kinds of chemicals in terms of volatility, solubility, etc.

Figure 2 shows the Ohio River Basin area studied. From this "figure 2 about here" figure a schematic of the basin was developed. Figure 3 shows the "figure 3 about here" symbols and general approach used in developing the schematic. Figure 4 shows the industrial discharges and the various water utilities "figure 4 about here" evaluated along the stretch of the River studied. The arrows pointing toward the line are discharges and influents from tributaries, the arrows pointing away from the line are various water utility intakes. As one proceeds from the Kanawha River downstream one can see that the first utility intake after the Kanawha enters the Ohio is the Gallipolis intake. In downstream order below Gallipolis are Huntington, Ashland, Ironton, Greenup, Portsmouth, Maysville, Cincinnati, Kenton County and Newport.

After developing the schematic of the river at its various reaches, the intakes, and the discharges, QUAL-II was used to simulate the priority pollutants discharged from each of the point sources shown in Figure 4. Priority pollutant concentrations at the water utility intakes under various flow conditions were calculated and then compared to water quality criteria taken from EPA published documents. Three different flow conditions were used to assess each utilities' vulnerability as shown in Table 1. The three conditions ranged from a high flow of 220,000 cu ft/sec "table 1 about here" and a low flow of 35,000 cu ft/sec. The average time of travel from the Kanawha headwaters to Cincinnati ranges from 2.4 days to 15 days, depending upon the various flows simulated.

After making numerous simulations of discharges in the Ohio River, some interesting tradeoffs between time of passage and pollutant characteristics were discovered. High flows dilute the discharge concentrations as might be expected, but the time of passage between the discharge and a given intake is shorter at high flows. Therefore at high flows the concentrations of volatile compounds at a given intake may be higher than at low flows. Figure 5 illustrates the point. Figure 5a shows a volatile compound at the three different flow conditions. At low flow the concentrations are low because of the long time of passage as compared to the high flow scenario. This occurs because volatility is highly time dependent. Figure 5b depicts a conservative pollutant at the three flow scenarios. The effects of dilution can be easily seen in this figure and illustrates an important interaction between chemical type, flow regime and utility intake location relative to the discharge that must be considered in evaluating a utilities' vulnerability to upstream discharges.

"figure 5 about here"

The ten utilities shown in Figure 4 were evaluated for their vulnerability to the various discharges shown. Three types of contaminants were examined: organoleptic pollutants; toxic pollutants; and carcinogenic pollutants.

Table 2 shows the organoleptic pollutants evaluated and the criteria against which they were examined.[8] Table 3 shows the results of the examination at the 10 and 100 percent level. The 10 percent level represents highly sensitive populations. As can be seen Ironton, Greenup, Portsmouth, Maysville, and in the Cincinnati area the 10% level is exceeded, under the low flow scenario.

"table 2 about here"

"table 3 about here"

Table 4 shows the toxic pollutants examined and the criteria levels used for evaluation. "table 4 about here" Table 5 summarizes the toxic pollutants that exceeded the health guidelines. "table 5 about here" In general, these toxic pollutants were exceeded at low flow when the concentrations were the highest. With the exception of mercury, these contaminants were exceeded only at the 10 percent levels.

Table 6 summarizes the results of the analysis for each of the utilities and each of the carcinogenic compounds examined. "table 6 about here" The expected deaths in excess of the various risk levels are shown in Table 6. The expected deaths per year rank the utilities in terms of this vulnerability to carcinogens. The least vulnerable utility according to the evaluation for the study states is Gallipolis, Ohio which is the first utility below the Kanawha.

In Figure 6 the utilities are plotted in downstream order. "figure 6 about here" Their vulnerability as determined by the carcinogenic category shown in Table 6 is given in parentheses.

Figure 7 illustrates the use of this approach in simulating spill events. "figure 7 about here" Figure 8 is a simulation of the carbon tetrachloride spill mentioned earlier. "figure 8 about here" In actuality two spills occurred. For purpose of this analysis only the last spill was modeled. As can be seen the model provides effective reproduction of the event. Having demonstrated the ability to simulate toxic discharge occurrences in the following section, the use of this approach is demonstrated in water treatment plant design or risk management.

5. RISK MANAGEMENT

In the previous section, methodology for simulating the effects of Toxic Waste Discharges was developed. In this section information on the concentration of various organics at a water supply intake will be used to design a water treatment system. Costs associated with various levels of water treatment or risk management will be evaluated. The application discussed will be developed in the context of a case study for the City of New Orleans which is located on the lower Mississippi River.

Figure 9 is a schematic of the lower Mississippi between Baton "figure 9 about here"
Rouge and New Orleans. This 100-mile stretch is one of the most heavily industrialized sections of waterway in the world. As with the Ohio River schematic the arrows pointing toward the line indicate industrial dischargers and the arrows pointing away from the line indicate municipal water supply intakes. Only "major industrial dischargers" were examined.

Data was acquired on industrial discharges upstream from the City of New Orleans. The sources included data from regional office files, the REACH file which defines segments of streams on a systematic and organized bases, the industrial facilities discharge file, and the pollutant matrix file.

Two types of analytical programs were utilized. The downstream influence analysis assumes discharge levels, disappearance rates, and tracks the concentrations to a given point in the stream. The upstream influence analysis assumes the concentration in a given point downstream and then tracks that concentration to an upstream point.[9]

In this analysis a set of concentration histories for two contaminants, TOC and Atrazine are examined and the cost of a technology to control these contaminants, GAC, is examined. These costs will provide the costs for Risk Management for a given set of water quality targets.

Figures 10 and 11 display average monthly concentrations of
"figures 10 and 11 about here"
Atrazine and TOC near the New Orleans raw water intake (Jefferson Parish). The solid lines on each figure illustrate three different levels of raw water quality: peak month, quarterly average, and yearly average. The dotted lines show three possible levels of finished drinking water. The dotted lines represent consumer exposure. Atrazine is a pesticide and TOC is a surrogate parameter that represents a group of organics. The costs of removing contaminants from various combinations of raw and finished water targets are incremental costs and as such represent an additional cost to the consumer.

Figures 12 and 13 are the loading curves for the two contaminants. As can be seen carbon is relatively less effective for TOC than for
"figures 12 and 13 about here"
Atrazine. These data coupled with cost data are used to calculate the costs for each treatment option.[10] For example, the cost of removing TOC from the three raw water levels shown in Figure 10 to a finished or drinking water level of 1 mg/L of TOC is shown in Figure 14. The
"figure 14 about here"
optimal cost for removing TOC is selected from Figure 14 and plotted in Figure 15 versus the finished water target. If removal from the
"figure 15 about here"
peak monthly effluent to a finished water target of 0.5 mg/L is chosen the cost will be 32¢/1000 gal.

Figure 16 is the same set of cost curves for removing Atrazine.
"figure 16 about here"

Another way to summarize these costs is to calculate the per family costs as shown in Tables 7 and 8.

"tables 7 and 8 about here"

The concept of the cost of risk management is best illustrated in Figure 17. The bottom curve is the cost of TOC removed versus percent removal. The dotted line represents benefits from removing TOC versus percent removal.

SUMMARY AND CONCLUSIONS

The authors have presented a method for evaluating the impact of toxic waste discharges on drinking water. A water quality model was used to define this impact and to provide the basis for development of a toxic screening model. Using the model, contaminant levels at drinking water intakes can be simulated. This information in turn drives design and cost decisions for technology. From these data the cost of risk management can be calculated.

A field scale study of this concept has been implemented involving the City of New Orleans, EPA Region VI and the American Water Works Association Research Foundation. The authors believe that there is promise in this approach and will ultimately compliment the development of information in risk assessment.

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Table 1. Hydraulic Characteristics for Daily Discharge Scenarios

Scenario	CFS* (X 1,000)	Time-of-Travel (Days)
High Flow	220.00	2.4
Avg. Flow	125.00	4.1
Low Flow	35.00	15.0

*Cubic feet per second

Table 2. Organoleptic Pollutants

Pollutant	Criteria (ug/L)
Copper	1000.0
Zinc	5000.0
Chlorobenzene	20.0
Nitrobenzene	30.0
Phenol	3000.0
2-Chlorophenol	.1
2,4-Dichlorophenol	.3
2,4,6-Trichlorophenol	2.0
Pentachlorophenol	30.0
2,4-Dimethylphenol	400.0
Acenaphthene	20.0

Table 3. Summary of Organoleptic Pollutants Exceeding Guidelines

Utility	Average Flow		High Flow		Low Flow	
	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis	None	None	None	None	None	None
Huntington	None	None	None	None	None	None
Ashland	None	None	None	None	None	None
Ironton	None	None	None	None	2-Chlorophonol 2,4-Dichlorophenol	None
Greenup	None	None	None	None	2-Chlorophonol 2,4-Dichlorophenol	None
Portsmouth	None	None	None	None	2-Chlorophenol	None
Maysville	None	None	None	None	2-Chlorophenol	None
Cincinnati Area	None	None	None	None	2-Chlorophenol	None

Table 4. Toxic Pollutants Examined

Pollutant	Criteria (ug/L)
Acrolein	325
a-Endosulfan	74
Endrin	1@
Antimony	146
Cadmium	10@
Chromium	50@
Cyanide	3770
Lead	50@
Mercury	.1440
Nickel	632
Selenium	10@
Silver	50@
Thallium	13
1,1,1-Trichloroethane	18400
1,3-Dichloropropene	87
1,3-Dichlorobenzene	400
1,4-Dichlorobenzene	400
Bis(2-chloroisopropyl)ether	34.7
Ethylbenzene	710
Toluene	14300
2,4-Dinitrophenol	70
4,6-Dinitro-o-cresol	13.4
Dimethyl Pthalate	313000
Diethyl Pthalate	350000
Dibutyl Pthalate	34000
Fluoranthene	42

Table 5. Summary of Toxic Pollutants Exceeding Health Guidelines

	Average Flow		High Flow		Low Flow	
Utility	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis	None	None	None	None	Cadmium	None
Huntington	None	None	None	None	Cadmium	None
Ashland	None	None	None	None	Cadmium Mercury	None
Ironton	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Greenup	Cadmium Mercury	None	Mercury	None	Cadmium Lead Chromium	Mercury
Portsmouth	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Maysville	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Cincinnati Area	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury

Table 6. Carcinogenic Vulnerability of Utilities at Various Flow Scenarios

Utility	Expected Deaths/ 100,000 at Average Flow	Expected Deaths/ 100,000 at High Flow	Expected Deaths/ 100,000 at Low Flow
Greenup, KY	6.47(1)	3.75(1)	19.77(1)
Portsmouth, OH	5.01(2)	3.14(2)	10.42(2)
Maysville, KY	2.99(3)	2.34(3)	2.39(3)
Cincinnati Area	1.56(4)	1.50(4)	0.56(4)
Ironton, OH	0.20(5)	0.13(5)	0.45(5)
Huntington, WV	0.19(6)	0.04(7)	0.44(6)
Ashland, KY	0.18(7)	0.11(6)	0.40(7)
Gallipolis, OH	0.02(8)	0.01(8)	0.07(8)

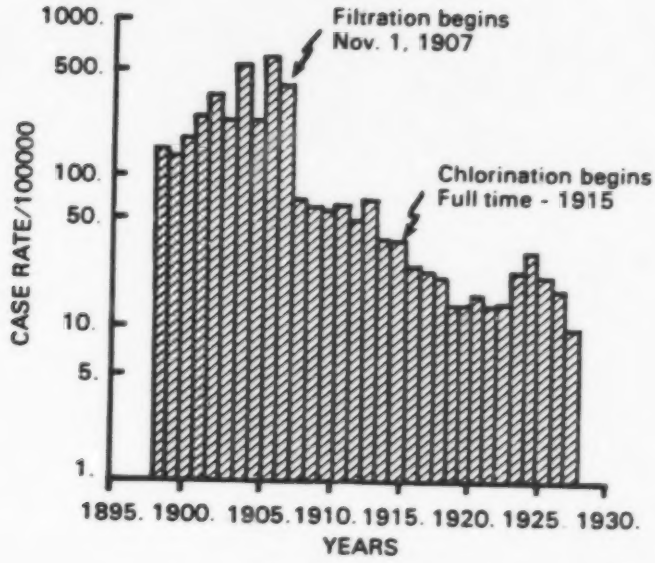
( ) Rank

Table 7. Incremental Household Costs to Meet Finished Water Targets

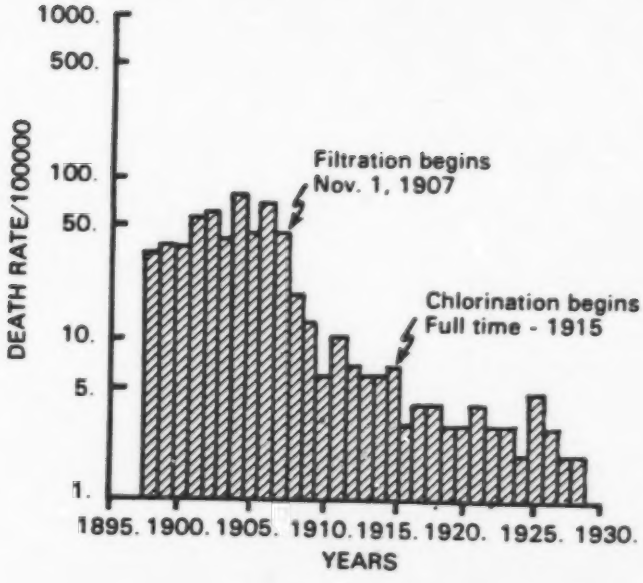
Atrazine Raw Water Influent	$/Household/Year Yearly Avg. (191 ug/L)	Quarterly Avg. (476 ug/L)	Peak Month (717 ug/L)
Finished Water Target			
50 ug/L	.26	.51	.70
25 ug/L	.28	.54	.74
10 ug/L	.31	.57	.76

Table 8. Incremental Household Costs to Meet Finished Water Targets

TOC Raw Water Influent	$/Household/Year Yearly Avg. (3.92 mg/L)	Quarterly Avg. (4.43 mg/L)	Peak Month (4.96 mg/L)
Finished Water Target			
1 mg/L	41.17	46.90	53.57
.50 mg/L	47.17	52.76	59.33
.25 mg/L	50.27	55.68	62.21



Typhoid cases over time



Typhoid deaths over time

Fig. 1 - Typhoid Cases and Deaths In Cincinnati, Ohio

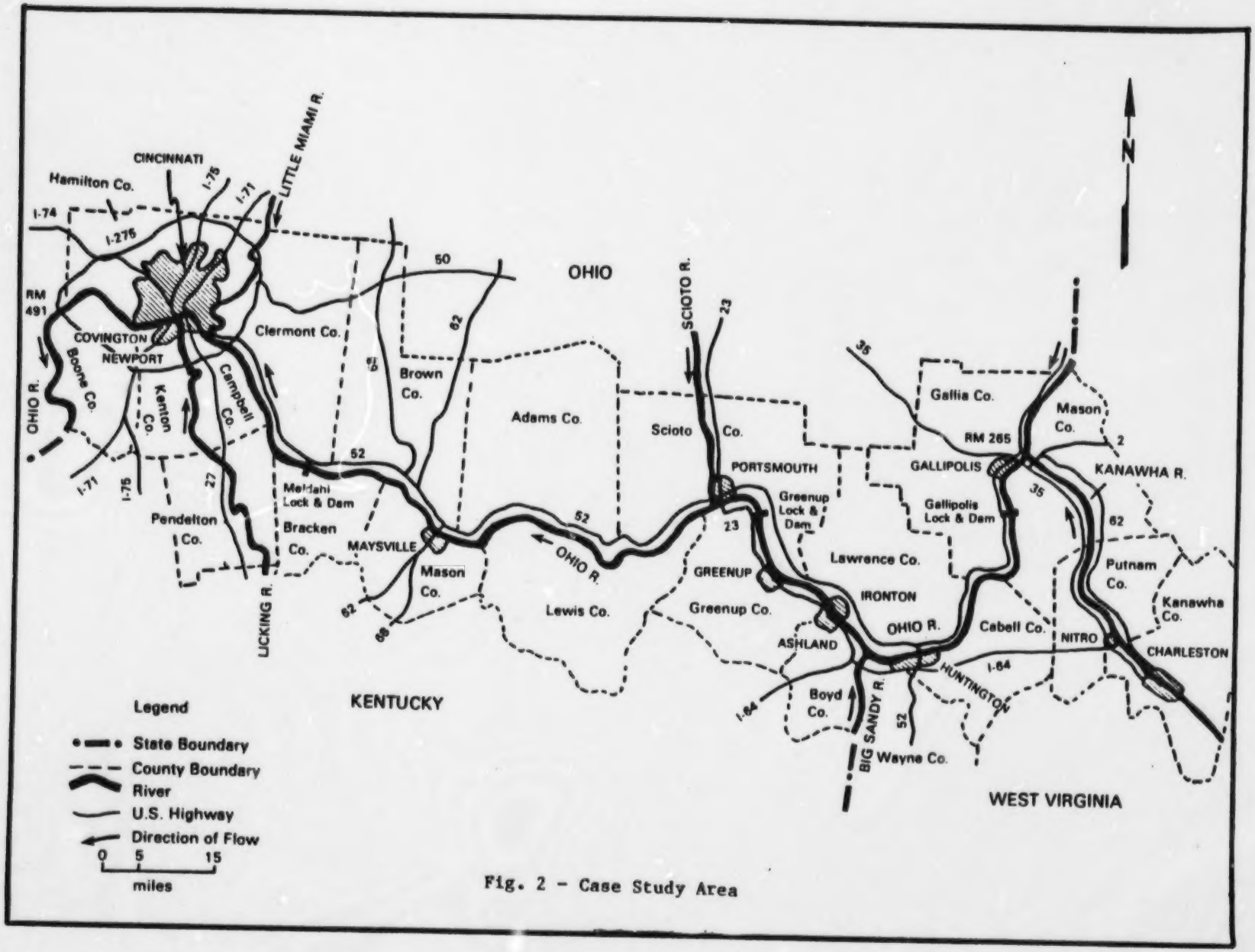
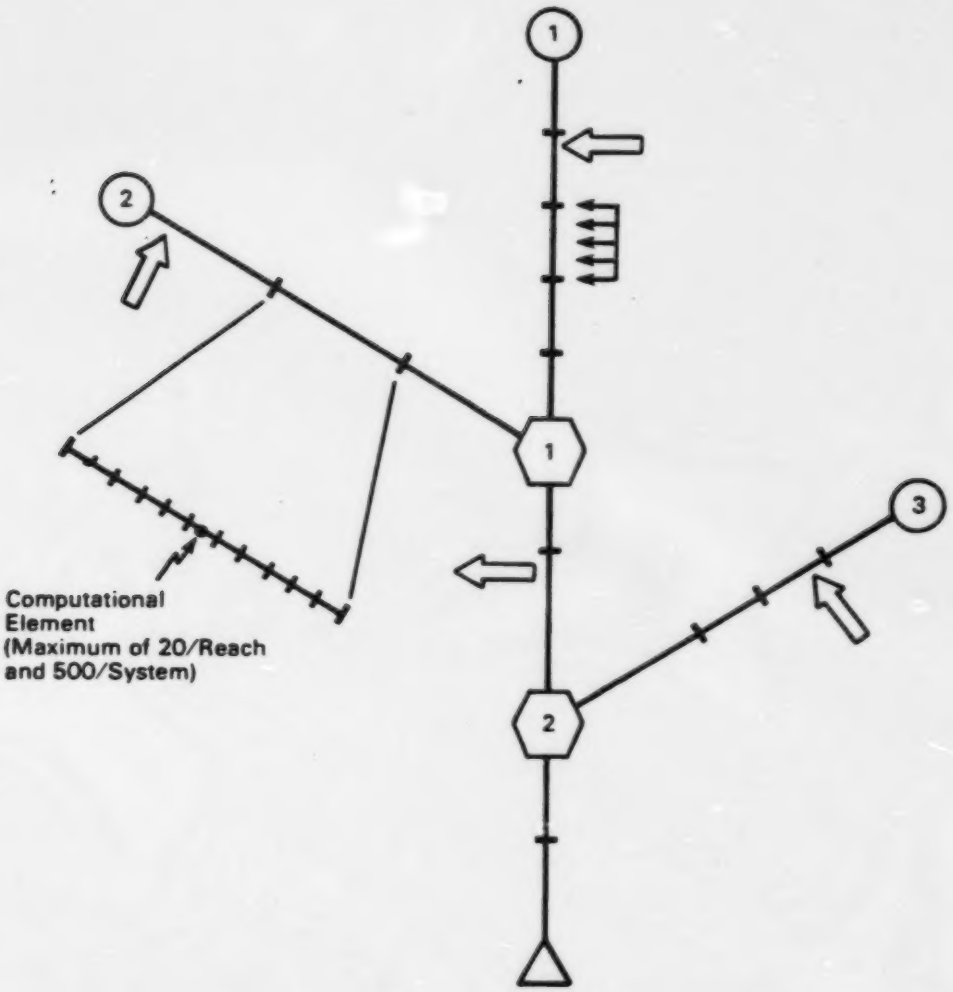


Fig. 2 - Case Study Area



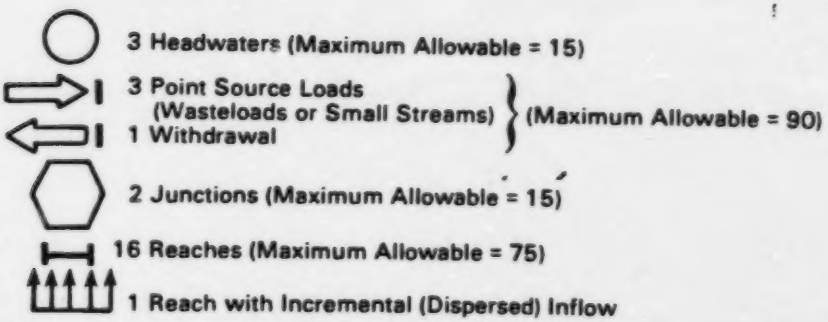

3 Headwaters (Maximum Allowable = 15)
3 Point Source Loads
(Wasteloads or Small Streams)
1 Withdrawal
(Maximum Allowable = 90)
2 Junctions (Maximum Allowable = 15)
16 Reaches (Maximum Allowable = 75)
1 Reach with Incremental (Dispersed) Inflow

Fig. 3 - Symbols For River Basin Schematic

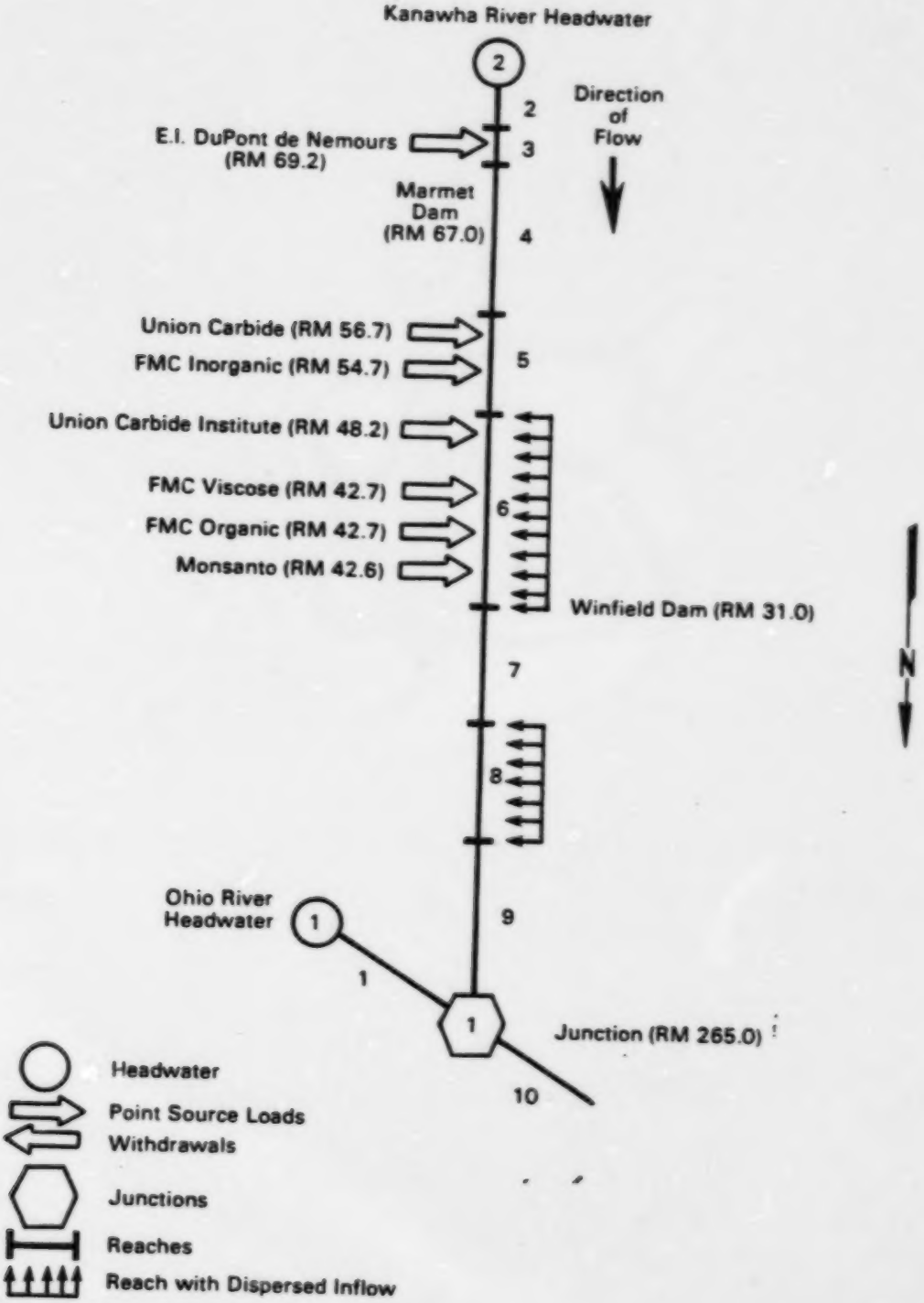


Fig. 4 - Ohio River Basin Schematic

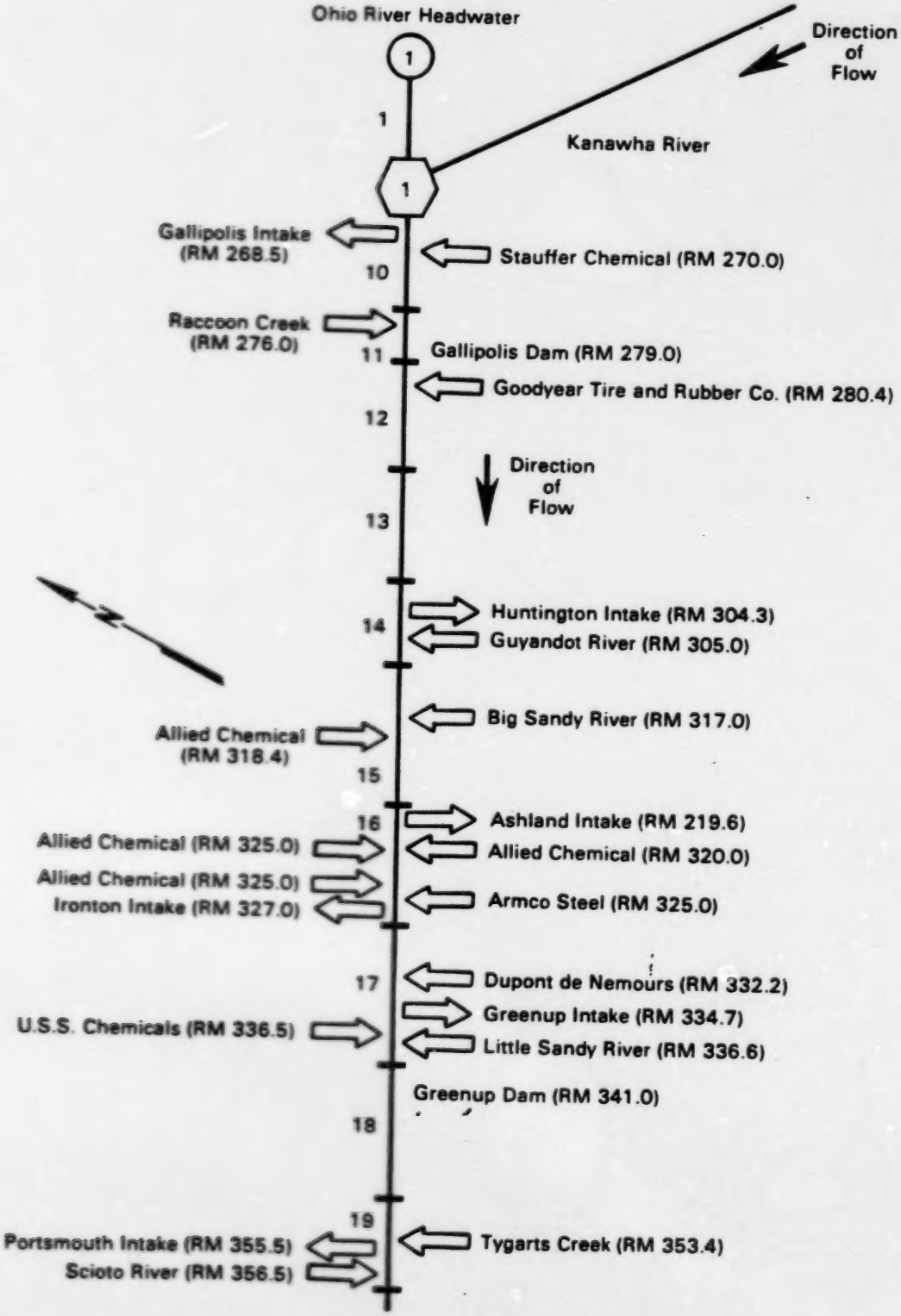


Fig. 4 - Ohio River Basin Schematic (cont.)

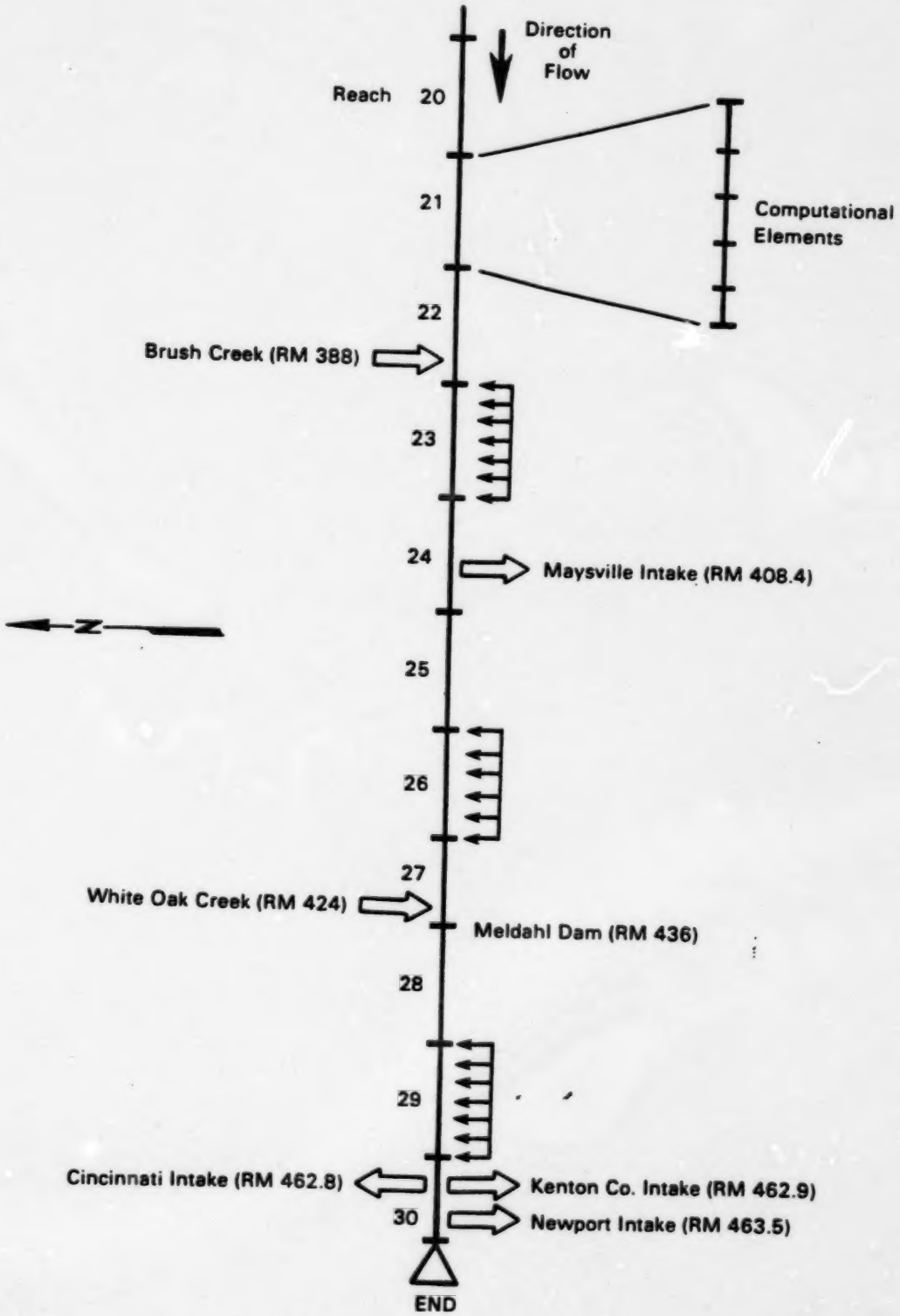
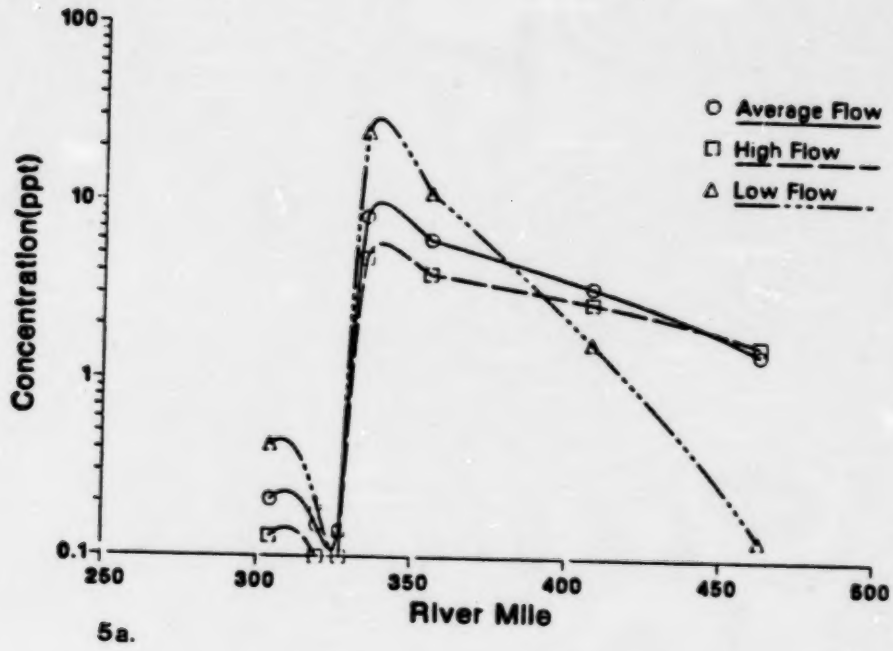


Fig. 4 - Ohio River Basin Schematic (cont.)



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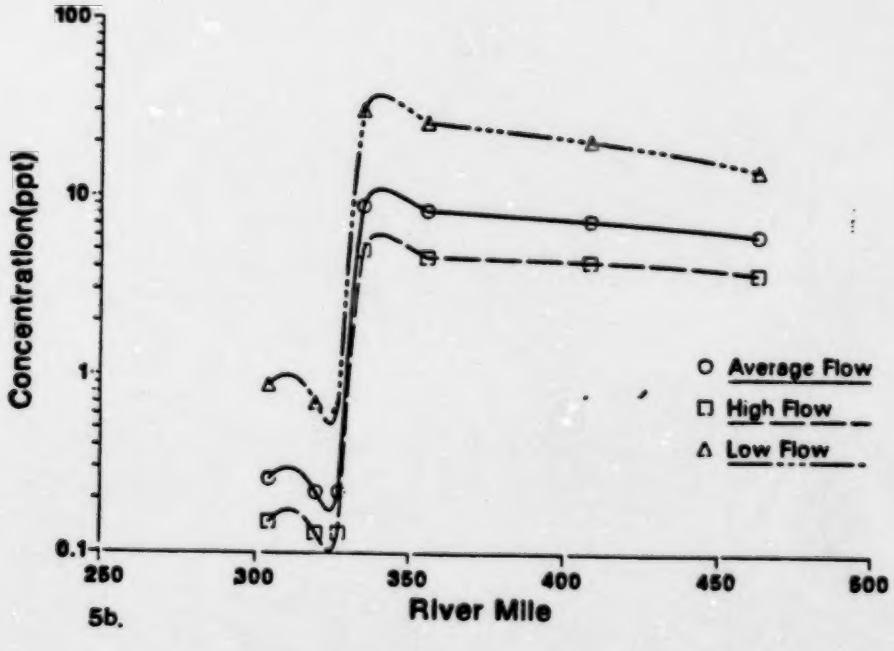

5b.

Fig. 5 - Volatile and Non Volatile Pollutant Characteristics at Various Flow Scenarios

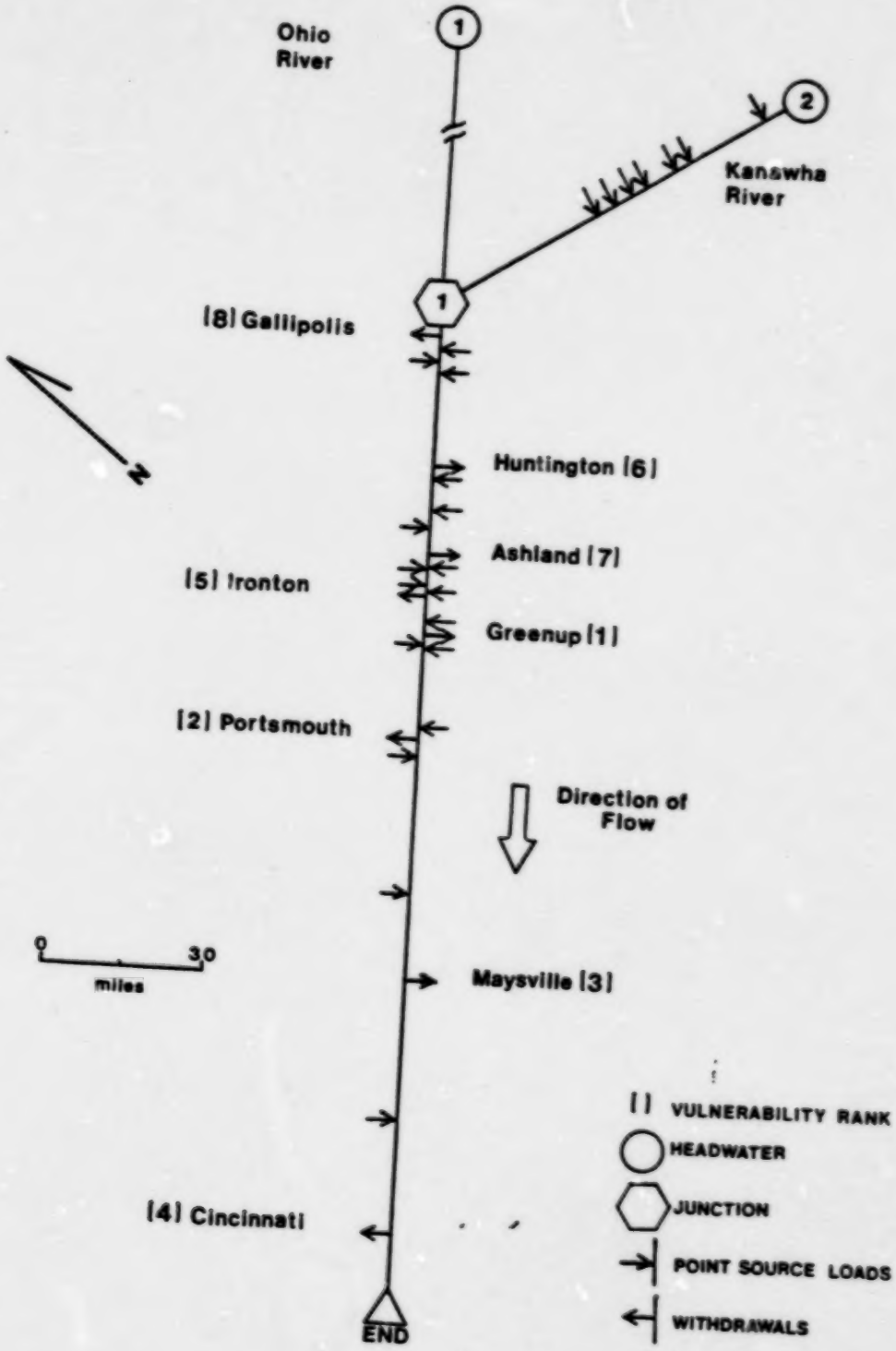

Fig. 6 - Vulnerability Ranking of Utilities

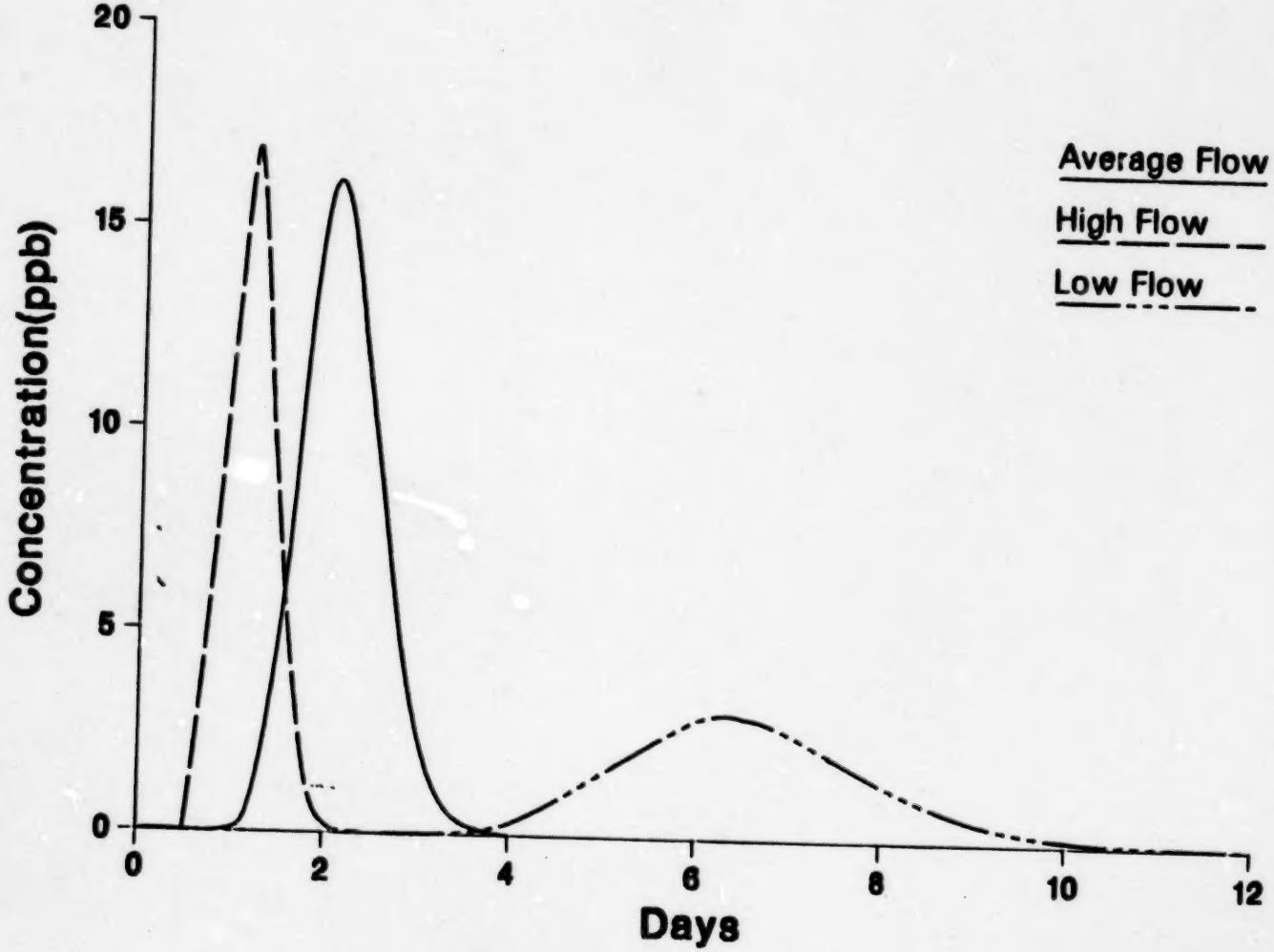

Fig. 7 - Spill Characteristics at Various Flow Scenarios

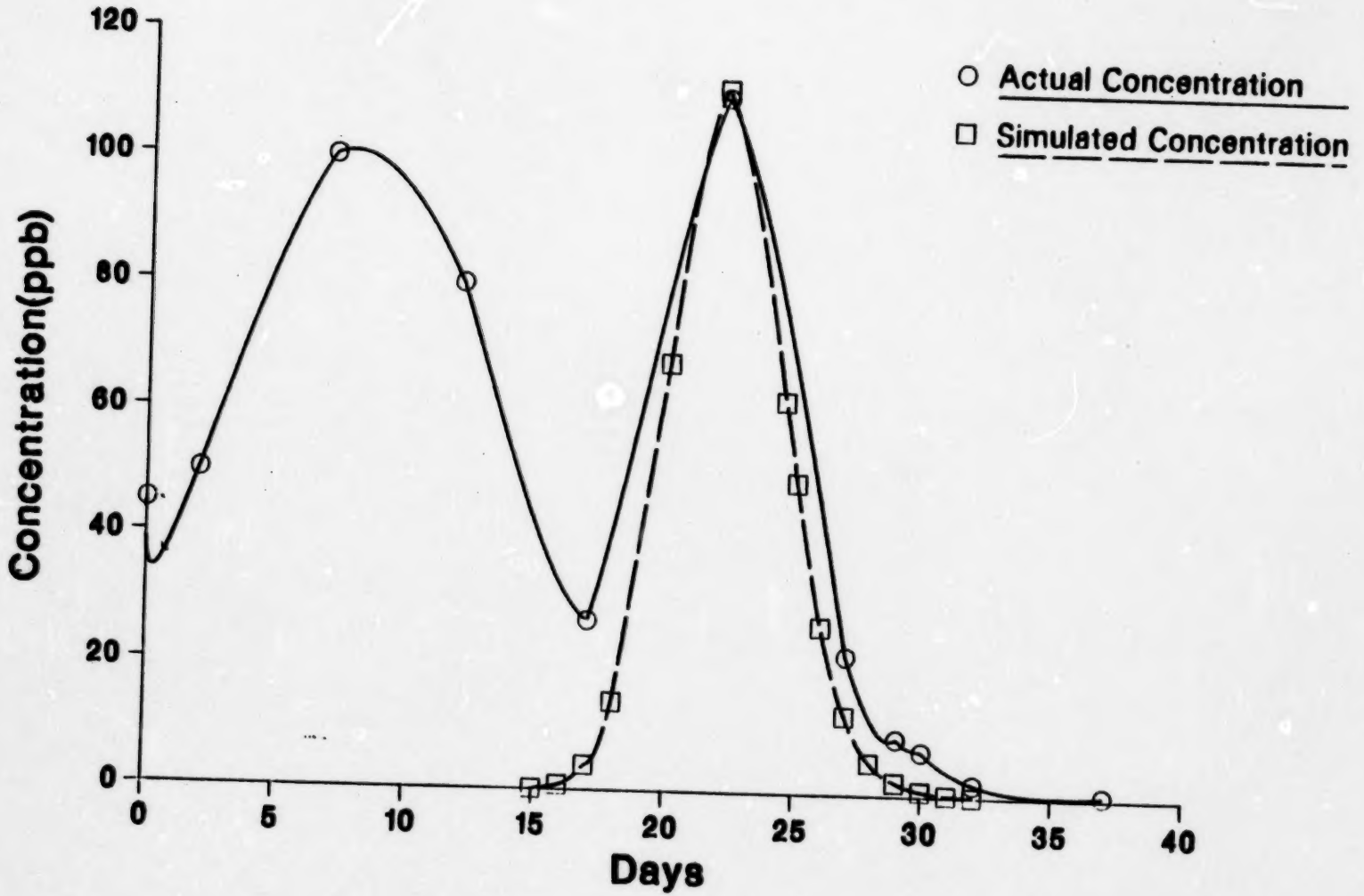

Fig. 8 - Actual vs. Simulated Carbon Tetrachloride Concentrations at Cincinnati, Ohio

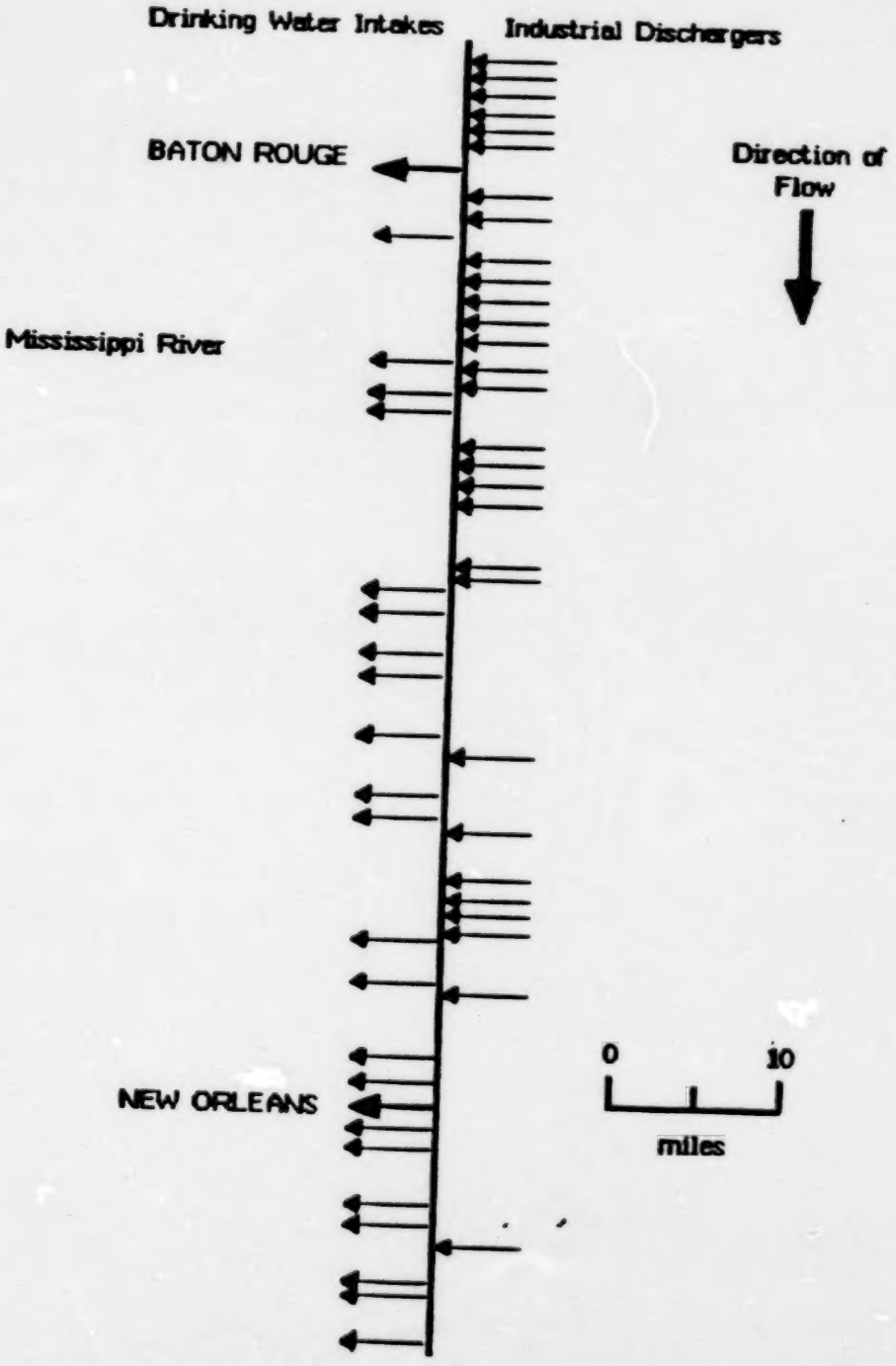

Fig. 9 - Mississippi River Schematic

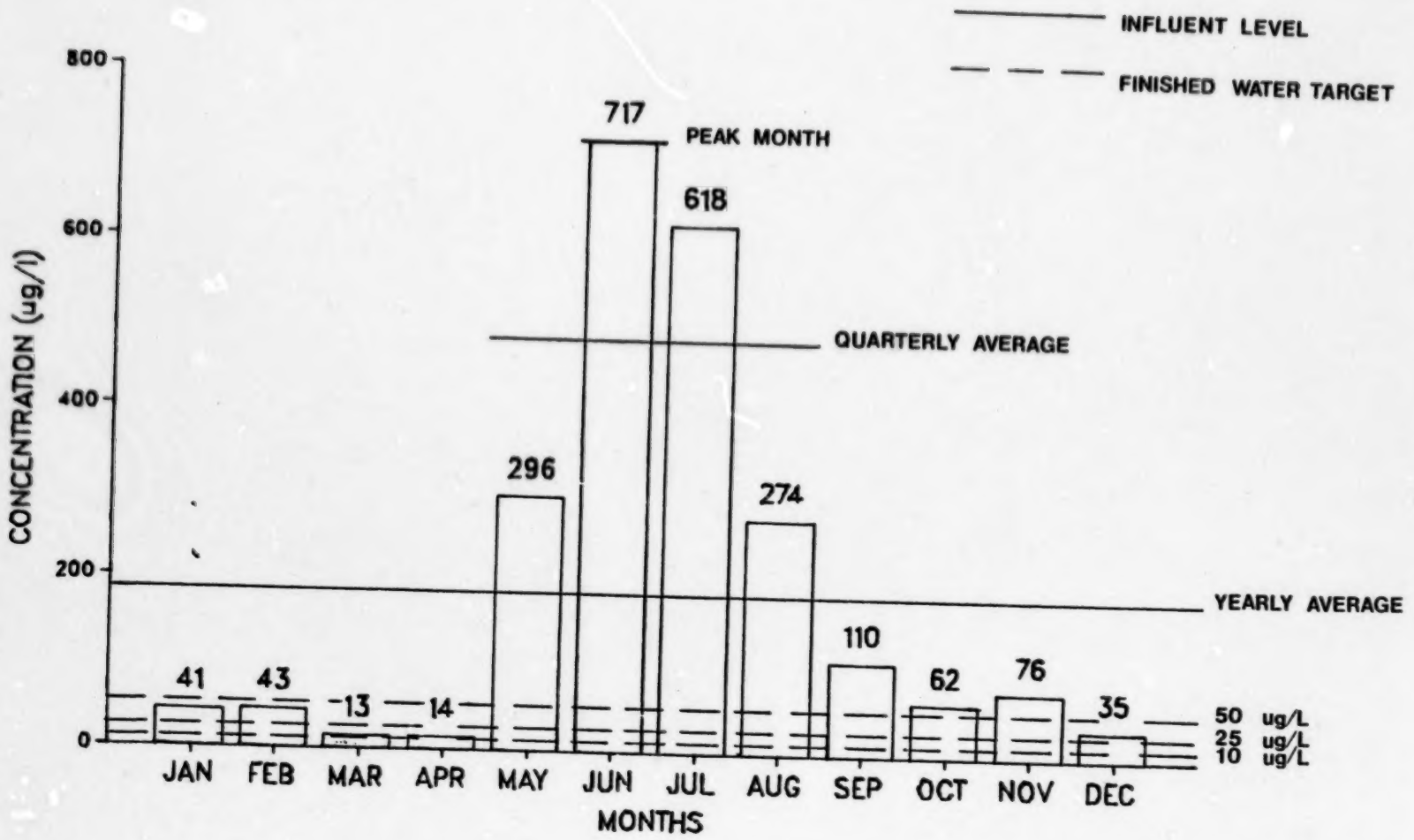

Fig. 10 - Average Monthly Raw Water Concentrations of Atrazine for Jefferson Parish and Finished Water Targets

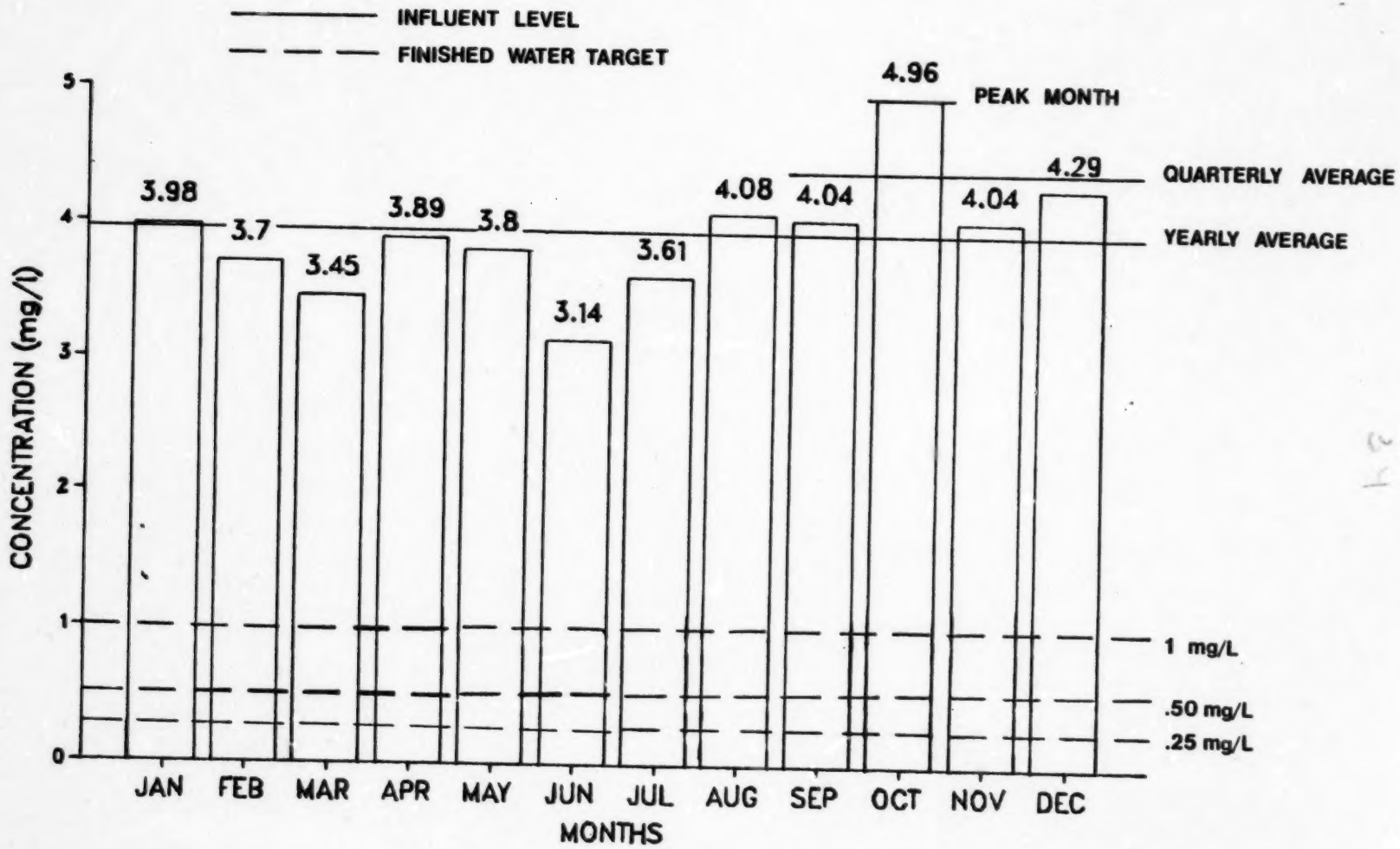

Fig. 11 - Average Monthly Raw Water Concentrations of TOC for Jefferson Parish and Finished Water Targets

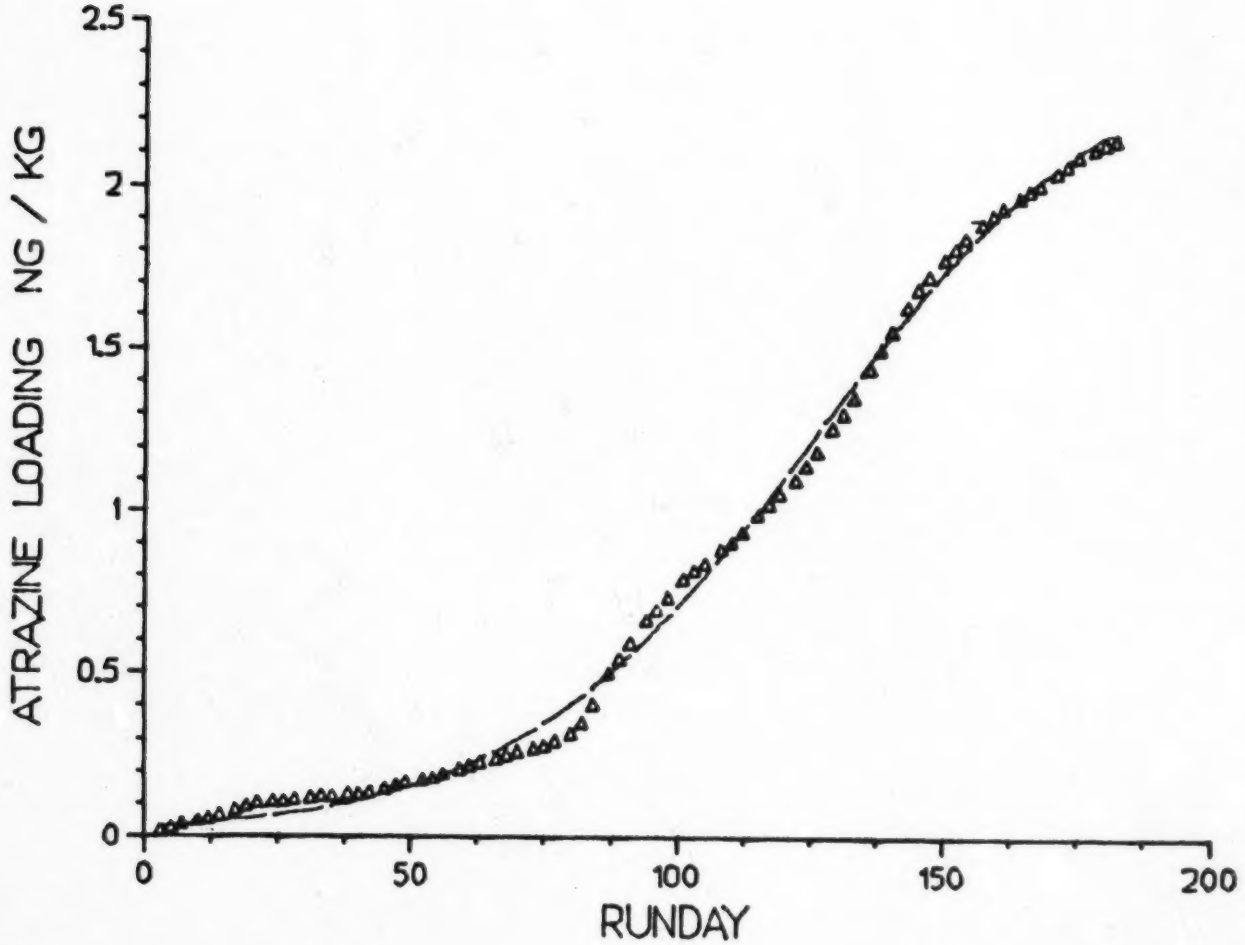

Fig. 12 - Atrazine Loading Curve for Jefferson Parish GAC System

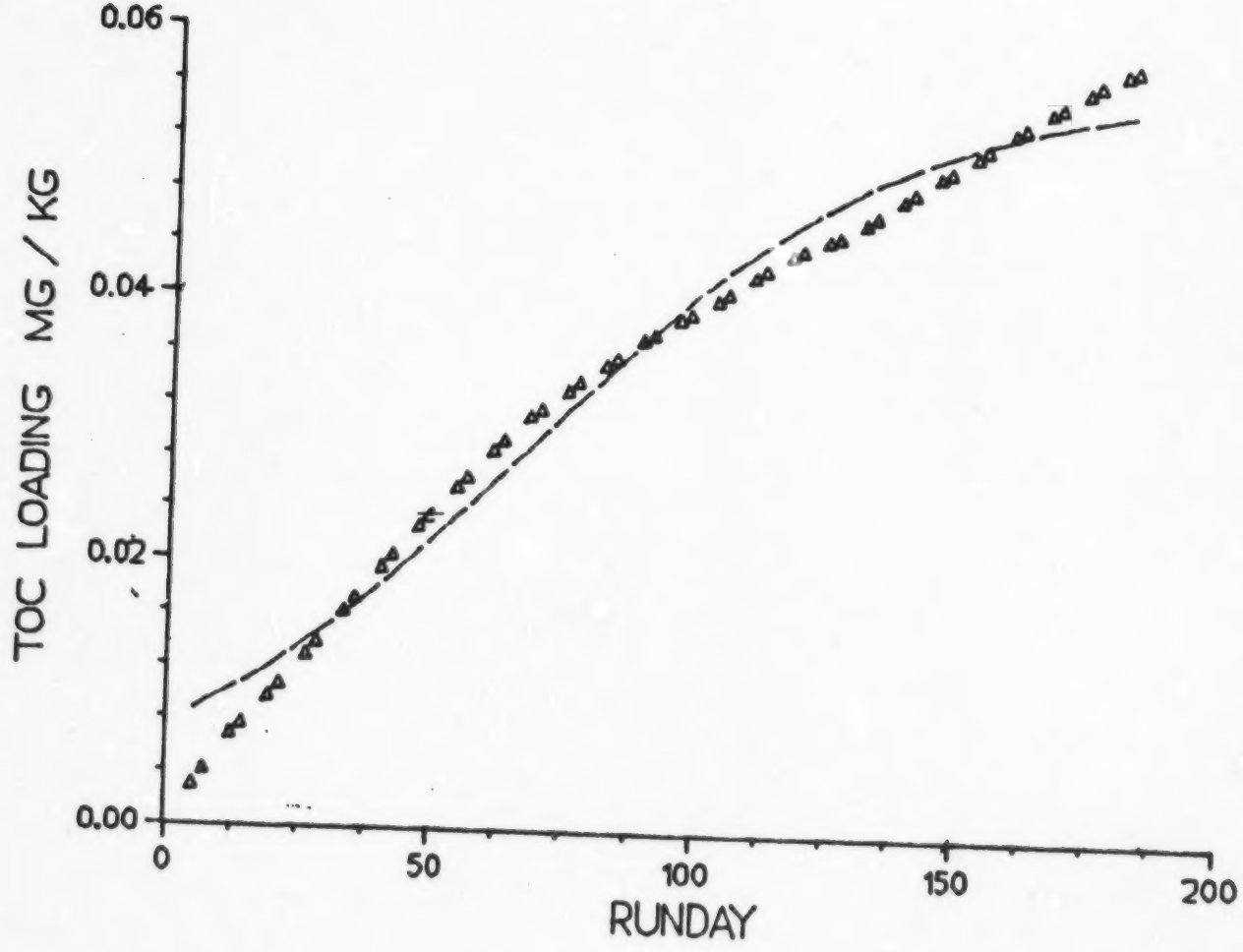

Fig. 13 - TOC Loading Curve for Jefferson Parish GAC System

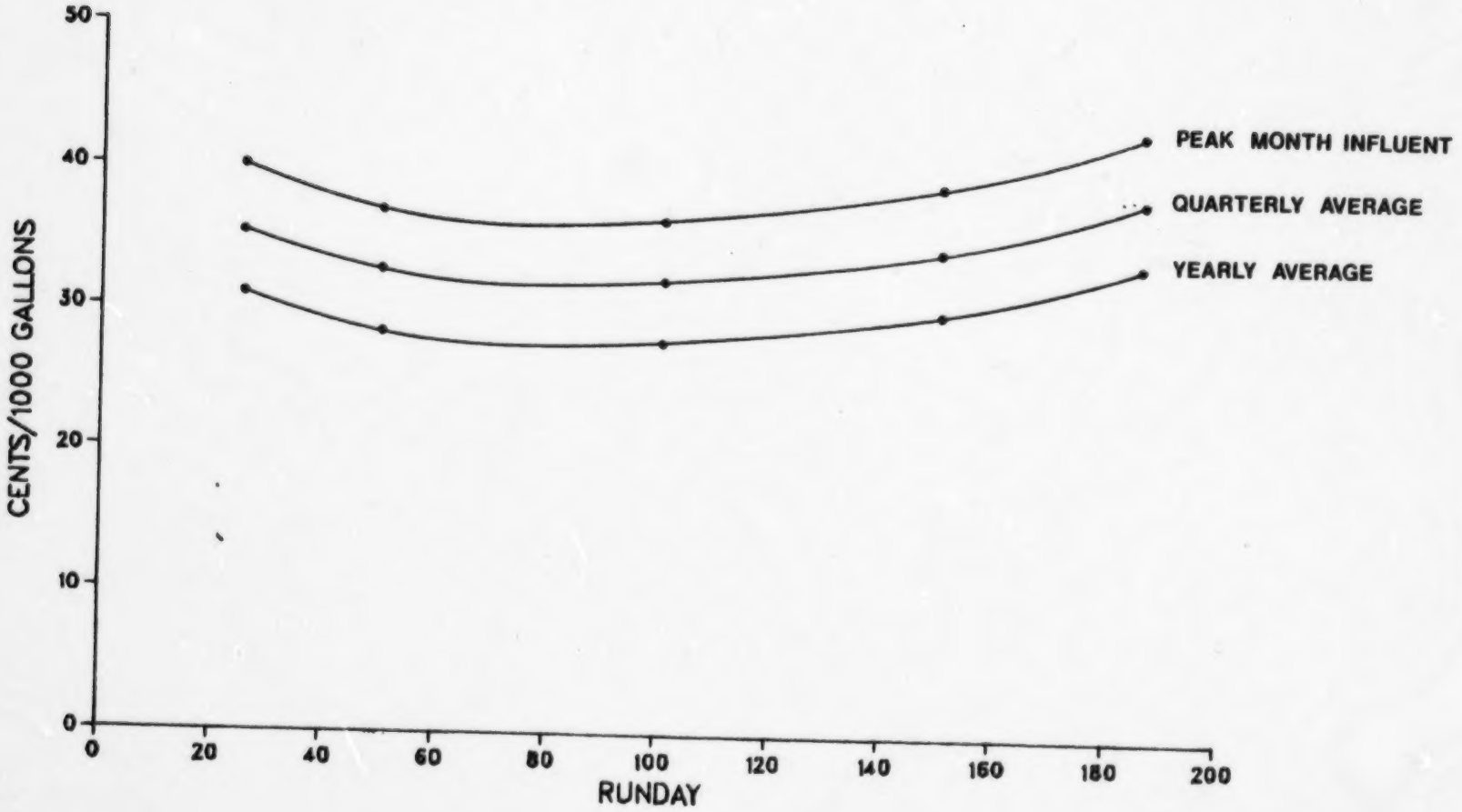

Fig. 14 - Cost of Meeting Finished Water Target of 1 mg/L TOC

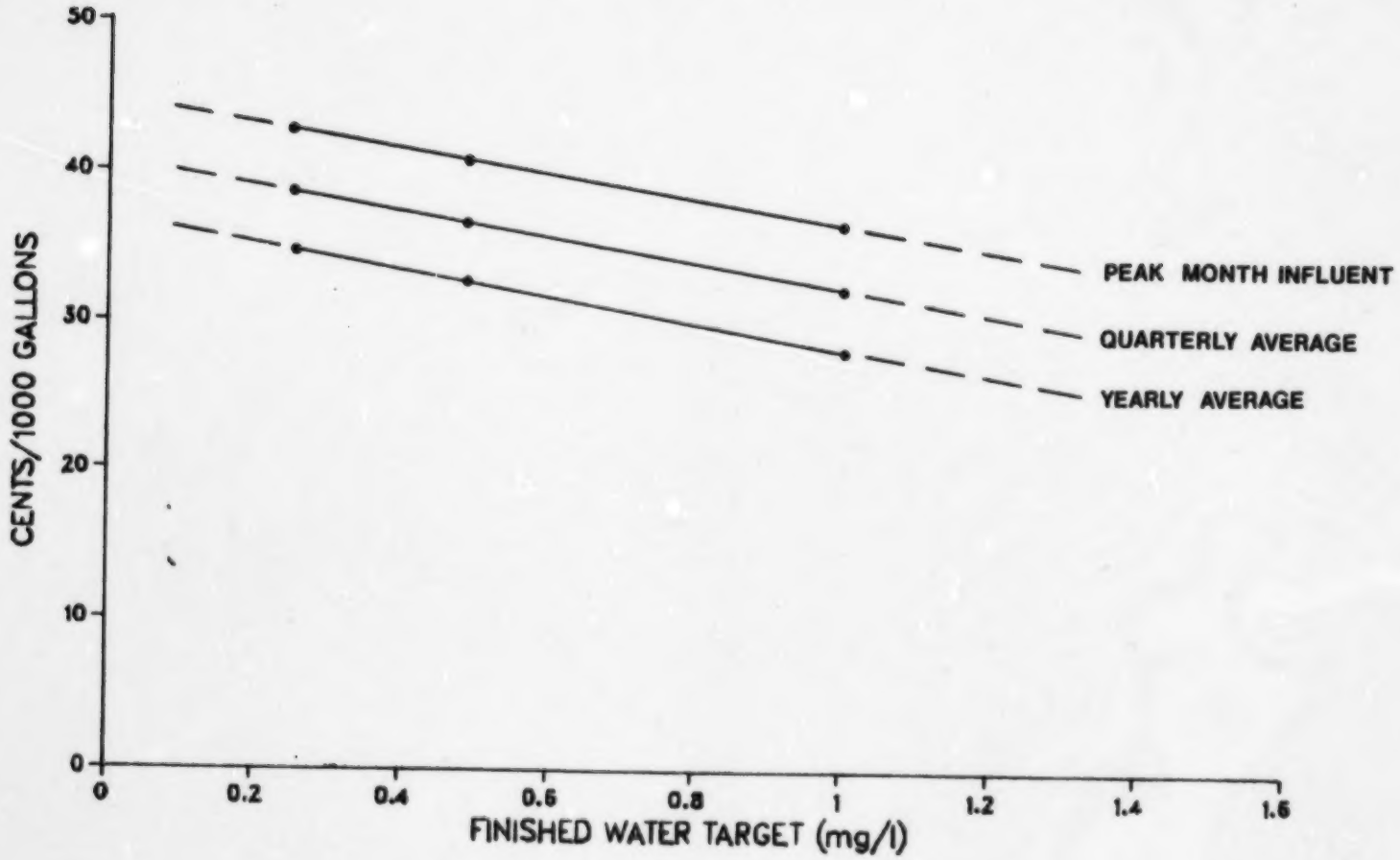

Fig. 15 - Cost of Meeting Various Finished Water Targets for TOC

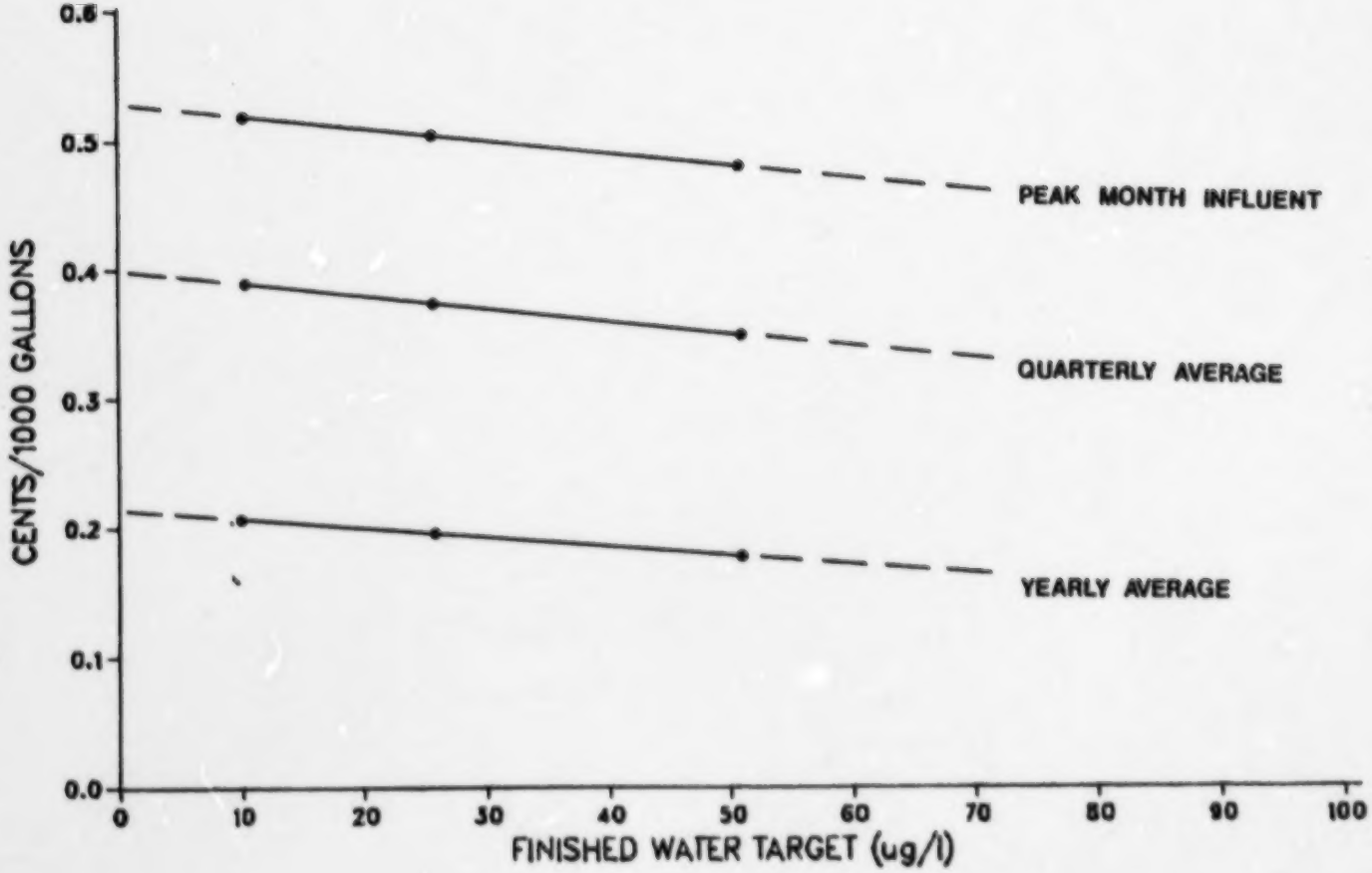

Fig. 16 - Cost of Meeting Various Finished Water Targets for Atrazine

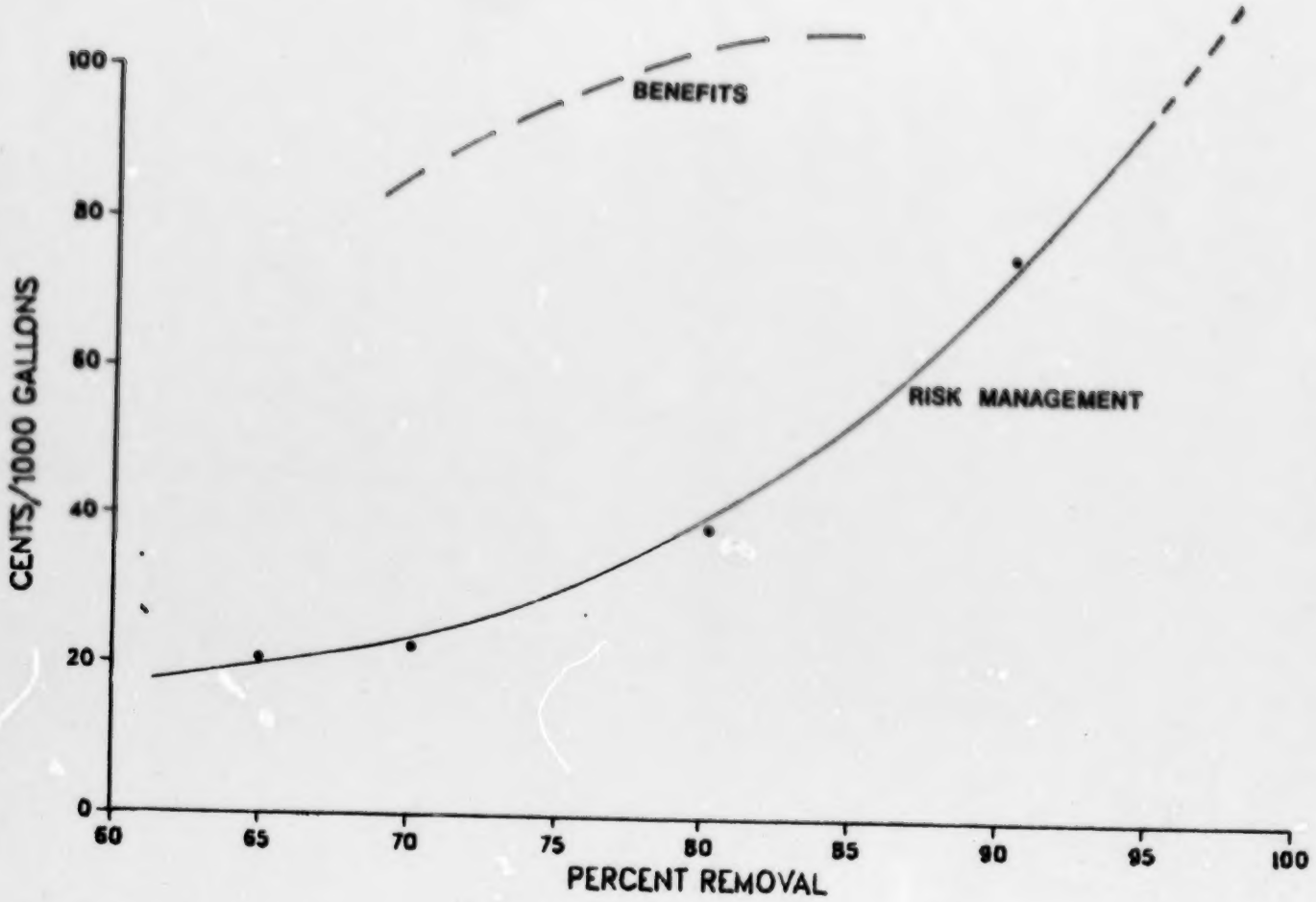

Fig. 17 - Cost of TOC Removal Versus Percent Removal